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A NEW SYNOPTIC SURVEY OF NORTHERN IRELAND LAKES: SAMPLING FROM THE AIR

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Introduction

Northern Ireland has approximately 1670 lakes, which cover 4.4% of the land surface. However, most of the water area is accounted for by the large lakes such as Lough Neagh (385 km^2) and Lower Lough Erne (109.5 km). The majority of lakes are less than 100 hectares in area. They tend to be distributed towards the south and west of the Province, where extensive drumlin swarms are rich in small waterbodies.

In 1988-1991, 610 of the 708 lakes between one and 100 hectares were sampled by the Northern Ireland Lake Survey. The objective was to assess their conservation status based on their aquatic macrophyte flora, but in addition to extensive plant surveys, the water of each lake was analysed for a range of chemical variables. The results of the survey were presented in an extensive report to the Department of the Environment (Northern Ireland). Although the report to DoE was unpublished, a bound copy is held in Queen's University Agriculture library and scientific papers based on the data are still being written (Smith et al. 1993; Gibson et al. 1995; Wu & Gibson 1996; Heegard et al. 2001). The sampling was carried out in the summer months with two teams each averaging two lakes per day. Because the survey was confined to the summer months, the nutrient data were a reflection of annual minimum rather than maximum values (Gibson et al. 1996). The survey occupied a protracted period, and at least for the nutrients, comparisons between lakes are not strictly valid since they could have been sampled months apart in the seasonal cycle and in different years throughout the three-year survey. Also, the data were taken at least eleven years ago and many changes are likely to have occurred in the intervening period.

With the requirements of the Water Framework Directive in mind, it was felt that a new survey should be conducted in late winter when nutrient concentrations are likely to be a true reflection of the trophic status of the lake. It was also felt that the lakes should be sampled over the shortest possible time interval and helicopter sampling offered this possibility. A trial series of eight lakes was sampled in August 2001, to test the sampling method and ensure that the helicopter did not produce any sampling artefacts such as disturbing the bottom sediments with the downdraft. This mission was highly successful. The samples were taken from a JetRanger helicopter carrying two scientists and the pilot. No problems were experienced with disturbance of the water, the downdraft being quite small from a helicopter of this type. In this article, we report on a full-scale survey carried out in early March 2002.

The survey

A list of 108 lakes to be sampled was supplied by the Department of the Environment, Northern Ireland (DoE), Environment & Heritage Service, who funded the project. Unlike the earlier Northern Ireland Lake survey, the lakes were not chosen by a stratified random method and so the results cannot be used to generalise the state of lakes in Northern Ireland. However, they provide a data set consistent with the objectives of the DoE in developing a lake classification and determining the state of some lakes of high conservation value.

Sampling began on 4 March, the earliest date possible after agreement of the contract. Weather that week was stormy and flying was impossible on Wednesday 7 March. Since the helicopter was based at Newtownards, Co. Down, there was approximately 40 minutes travel time to the furthest lakes. Originally it was planned to stay overnight in Fermanagh on the 5 March, but this was deemed inadvisable because of the bad weather. If this had happened, there would have been a considerable saving of travel time. Apart from the weather and problems in finding some lakes, sampling went very well. In spite of the strong winds the following schedule was achieved (see Fig. 1):

4 March	30 lakes	Fermanagh & Tyrone
5 March	35 lakes	Fermanagh
7 March	40 lakes	Armagh & Down
12 March	8 lakes	Antrim Plateau.

Flying would have been possible on Friday 8 March, but flying the remaining eight lakes on the Antrim Plateau was postponed until 12 March so that the samples could be analysed during normal working hours on 13 March.

Finding the correct lake was not a trivial task, partly because of the heavy rain in the days preceding the survey. At least one lake had spilled over into the surrounding fields and it is probable that the area sampled

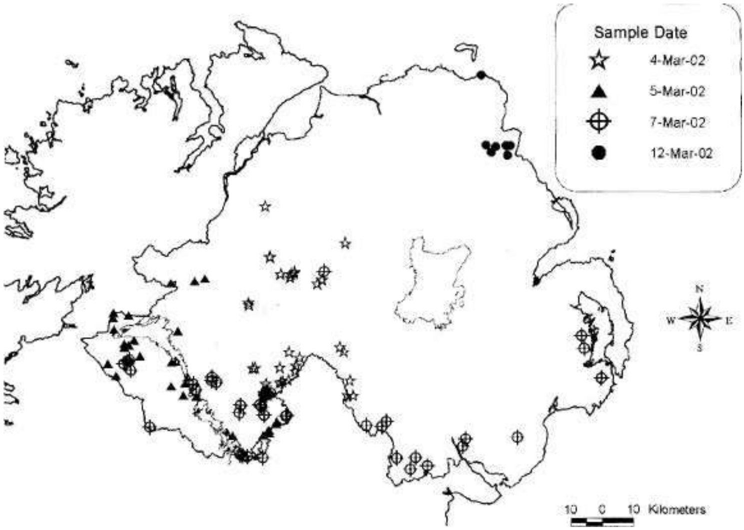


FIG. 1. Lakes sampled by air in March 2001.

was outside the normal lake basin. Other lakes were difficult to identify in the poor weather. Some lakes were revisited on 7 March to ensure the sampling was correct. Subsequent analysis of the GPS data verified the position of the lakes and revealed that three lakes were not sampled and one lake was sampled twice. Lough Formal (area 8 hectares, altitude 20 m) was sampled twice, firstly on 5 March and again on 7 March, providing an insight into the likely replication errors. The results were satisfactory (Table 1) although the soluble reactive phosphorus (SRP) concentration was noticeably different between the two samples.

Table 1. Analytical data from repeat visits to Lough Formal. SRP, soluble reactive phosphate; TSP, total soluble phosphorus; TP, total phosphorus; OD, optical density.

	pH	Conductivity $\mu S\ cm^{-1}$	SRP $\mu g\ l^{-1}$	TSP $\mu g\ l^{-1}$	TP $\mu g\ l^{-1}$	NO_3-N $mg\ l^{-1}$	OD_{340}
5 March	7.0	80	4	13	17	0.11	0.204
7 March	6.9	84	10	11	15	0.14	0.206

Sampling by helicopter

Two scientists were carried in the rear seat of the helicopter. The door panel behind the pilot was removed to allow sampling as the windows of the craft are too small to allow the sampler to be deployed. However, flying with the door off exposes the outside scientist to considerable wind chill and even with appropriate warm clothing it was chilly work. During sampling, the helicopter hovered at approximately 7 m above the water in the centre of the lake.

A sampler was developed in our test tank. It consisted of a plastic carrier sleeve weighted with lead. A 1 litre plastic bottle was inserted in the sleeve and held in place by a bungee cord. The weight of lead was trimmed to allow the bottle to sink slowly once it entered the water. It thus took an integrated sample over the depth of its travel. Although the rate of sinking increased as the bottle filled, tank tests showed that it took water in throughout its descent. A float was positioned on the rope 1 m above the sampler to prevent sinking below this depth.

A list of lakes with Irish Grid References (IGR) was supplied to the helicopter company. All lakes to be sampled were marked on a set of maps for the use of the scientific staff. The helicopter pilot was responsible for locating the lake from his maps and for deciding on the order in which they were sampled. Once onsite, the pilot read out the position from the onboard GPS and this was noted by the inside scientist. The two scientists worked as a team. The scientist on the outside seat behind the pilot was responsible for taking the samples. His colleague on the inside seat changed the bottles in the sampler and kept records of the GPS reading. Lakes were flown in groups in two-hour sectors. At the end of the sector, the helicopter landed, refuelled and the scientific crew changed over if planned. After the survey, all GPS readings were converted into Irish Grid references and compared with the Irish Grid references given for the lakes in Smith et al. (1991) to ensure the correct lake had been sampled.

Chemical analysis of lake samples

Samples were returned to the laboratory at the end of each day and stored in the dark at 4°C. Analyses were carried out the following day by staff of the Agricultural and Environmental Science Division. Full data from the analyses were reported to DoE, but summary statistics are shown in Table 2 and Figs 2-7.

Table 2. Summary statistics of all lakes sampled. Average is arithmetic mean, except for pH which is median.

	pH	Conductivity µS cm^{-1}	SRP µg l^{-1}	TSP µg l^{-1}	TP µg l^{-1}	NO_3-N mg l^{-1}	OD_{340}
Maximum	8.4	543	222	223	264	4.5	0.80
Minimum	4.0	46	1	1	5	0.0	0.01
Average	7.5	200	13	21	41	0.6	0.14

Phosphorus

Soluble phosphorus fractions were determined after filtration through a pre-washed 0.45 *µm* pore-size membrane filter by the ascorbic acid-molybdate method of Murphy & Riley (1962) on a filtered undigested sample (soluble reactive phosphorus, SRP) and a digested sample (total soluble phosphorus, TSP). Total phosphorus (TP) was determined after digestion of an unfiltered sample. Digestion was by the persulphate digestion method of Eisenreich et al. (1975).

The frequency distribution of phosphorus concentrations, in the various fractions, is shown in Figs 2-3. It was surprising that there were so many low SRP values, suggesting perhaps the spring bloom had already started, but the TP data are more as expected with many values over 50µg 1^{-1} . TP values less than 10 fig l^{-1} were found in lakes Atona, Cashel Upper, Lake 110 Unnamed, Cam, Tullywannia, Navarad and Oak, and values over 100 µg l^{-1} in Bresk, Muck, Fireagh, Vearty, Coranny, Unshinagh and Natroey:

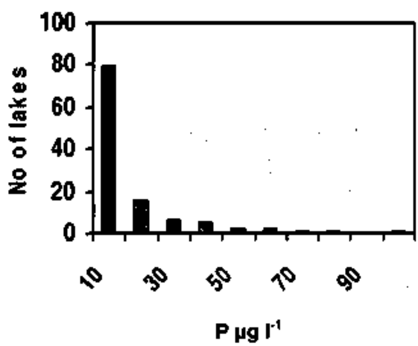


FIG. 2. Frequency distribution of concentrations for soluble reactive phosphorus in all the lakes sampled (µgP 1^{-1}).

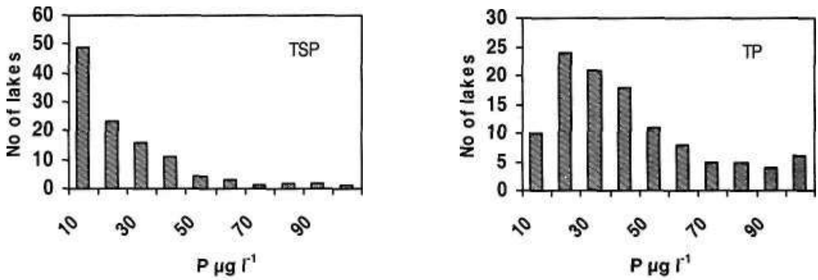


FIG. 3. Frequency distribution of concentrations for total soluble phosphorus *(left)* and total phosphorus *(right)*, in all the lakes sampled (µg P1^{-1}).

Nitrate-nitrogen

Nitrate-nitrogen (Fig. 4) was determined after reduction to nitrite by copper sulphate and hydrazine (Chapman et al. 1967). The nitrate-N values followed a similar pattern to those for SRP in that many values were in the lowest category. Approximately half the lakes had concentrations of less than 0.25 mg N1^{-1} and some of the upland lakes such as Cam, Narye, Meenaghmore, Loughnatrosk and Loughnafanoghy contained less than 0.025 mg N1^{-1}. Some lakes on the other hand were markedly enriched with N; most notably Derryleckagh and Greenan had over 4 mg N l$^{-1.}$

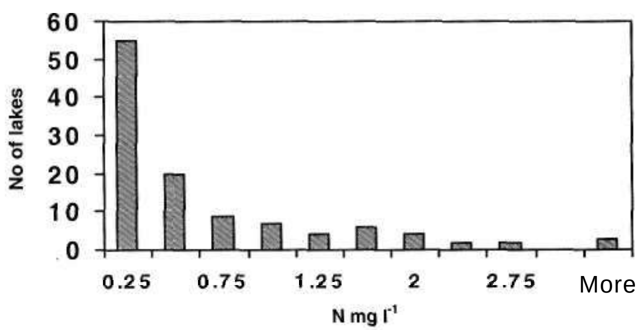


FIG. 4. Nitrate-nitrogen concentrations (mg N l^{-1}) in all lakes sampled.

pH & conductivity

Electrical conductivity (Fig. 5) was determined by a Phillips PW5909 digital conductivity meter calibrated by reference to a certified reference standard of 100 µS cm^{-1} and results were corrected to 25 °C using the in-built temperature coefficient for the meter. Measurements of pH were determined using an Orion EA90 ionmeter, using separate glass and KC1 reference electrode calibrated by two certified buffer solutions.

The pH of the majority of lakes was in the range 6.5 to 7.0 (Fig. 6), but there were some strikingly acid lakes, notably Loughnafanoghy, Loughnacrackin, Sallagh, Oak, Loughanalbanagh and Navarad which all had pH less than 4.5. The acid lakes were also dilute, with low conductivities, but not all dilute lakes were the most acid. Lakes Loughanalbalnagh, Mill, Shannagh, Loughnafreaghoge, Navarad and Carnmore all had conductivities less than 50 µS cm^{-1} ; by contrast, the hardest water lakes were Tullybrick and Unshinagh on the Lower Calp limestones of South Fermanagh with conductivities over 500 µS cm^{-1}. The range of conductivity values recorded is shown in Fig. 5.

Colour

Dissolved organic matter absorbs short wavelength light strongly, but has little absorbance at long wavelengths. Accordingly, colour (Fig. 7) was determined by measuring the optical density (OD) of an unfiltered sample at 340 nm and a reading at 700 nm was subtracted to give a value corrected for turbidity in the sample. Colour is caused by dissolved humic substances

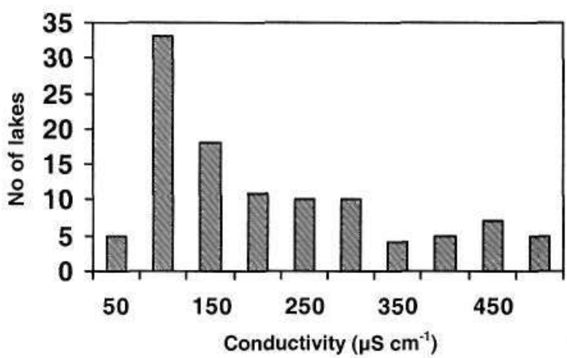
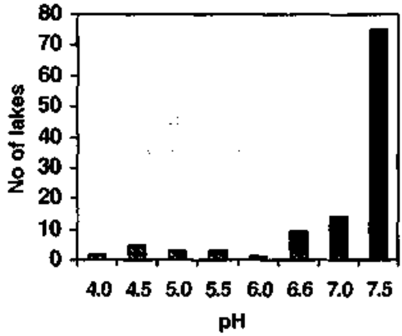


FIG.5. Electrical conductivity (µS cm^{-1}) in all lakes sampled.

FIG.6. Values obtained for pH.



4.0 4.5 5.0 5.5 6.0 6.6 7.0 7.5
pH

from the catchment soils. Rainfall, spring-fed or carbonate lakes typically have low colour whereas upland lakes with peaty catchments can be highly coloured. The extreme example in this survey was Lough Shannagh in the Mournes with OD_{340} of 0.74. The clearest lakes were Tullybrick, Atona and Fardrum, which had colour values of less than 0.04.

Concluding remarks

The data set obtained could not have been obtained in any other way. A synoptic data set of this kind is very unusual and will be used in the second phase of the project to calibrate nutrient export models. For this, the samples provide a snapshot akin to the satellite imagery and digital aerial photographs that will be the basis of the land use classification for the lake

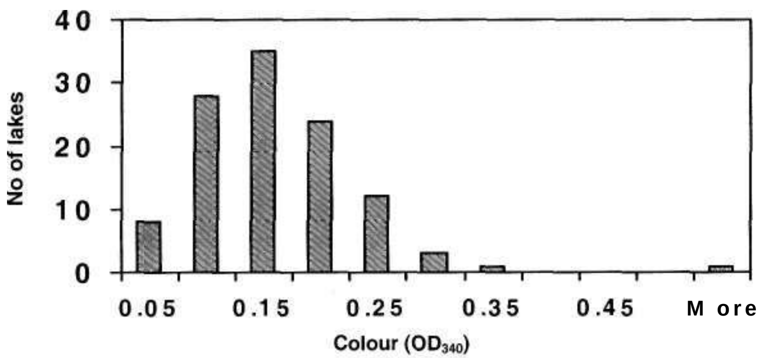


FIG.7. Colour values (OD_{340}).

catchments. The lakes also provide a wide range of values for all the variables measured, which is helpful in verification. Aside from the scientific advantage of sampling lakes at the same stage of the annual cycle, it is very efficient. Samples were analysed very close to the time of sampling thus reducing the problems of handling and storage that would arise if the lakes were sampled over several weeks by traditional methods. In addition, the economics of helicopter sampling are favourable. One hundred and ten lakes sampled in this way over four days with two scientific staff cost less than £100 per lake. The helicopter hire was £450 +VAT per hour. To be sure of achieving our objective, we negotiated a fixed price for the job with the company. This was probably wise but, under more favourable conditions and with less travel time, considerable savings could have been made in helicopter time thereby reducing the price per lake sampled. On the other hand, sampling by boat on the lake would cost approximately 110 man-days plus subsistence, which equates to £250 per lake. Sampling from the lake margin without a boat would allow more lakes to be sampled in a day, but even so, the cost of helicopter sampling still compares favourably. This is especially true if you include the substantial extra effort required in a land based survey to collect samples and transport them back to the laboratory, and the added analytical costs of storage for later analysis.

Acknowledgements

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